NACA TN 4403

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4403

TESTS OF RING-STIFFENED CIRCULAR CYLINDERS SUBJECTED TO A TRANSVERSE SHEAR LOAD

By James P. Peterson and Richard G. Updegraff

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
September 1958

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 4403

TESTS OF RING-STIFFENED CIRCULAR CYLINDERS SUBJECTED TO A TRANSVERSE SHEAR LOAD

By James P. Peterson and Richard G. Updegraff

SUMMARY

Thirty-four circular cylinders stiffened by heavy rings were loaded to failure in combined bending and shear with a transverse shear load. The results are presented in the form of an interaction curve which is applicable to the design of ring-stiffened cylinders that fail as a result of local buckling.

INTRODUCTION

Aircraft designers must consider the relative merits of several types of construction in the process of selecting a fuselage for a new aircraft or missile. The type most likely to be selected on the basis of simplicity alone is the ring-stiffened shell. Accordingly, it may be the final choice if other considerations appear to balance one another. Such a balance can result in designs ranging from fuselages of high loading intensity on the one hand to lightly loaded, but pressurized, fuselages on the other hand.

Reference 1 presents the results of some bending tests on cylinders stiffened by heavy rings. Considerably larger loads were obtained in the tests reported therein than had been obtained earlier by various investigators on one-bay cylinders clamped between heavy end fixtures. This result suggests that the one-bay specimen has irregular stress distributions or "soft spots" near the ends of the specimen in excess of those existing in ring-stiffened cylinders. These irregular stress distributions may cause premature local buckling. A corresponding discrepancy between the results for one-bay cylinders and those for ring-stiffened cylinders may be anticipated for cylinders subjected to the simultaneous action of bending and shear.

The tests reported herein are intended to be useful in the design of nonpressurized, ring-stiffened shells. The tests were made on circular cylindrical shells loaded in combined bending and shear by a transverse shear load. In order to study the local instability of such structures, the rings were made heavy and general-instability-type failures which involve the simultaneous failure of the cylinder wall and rings were thereby eliminated. The parameters varied in the tests were the ratio of ring spacing to radius, the radius-thickness ratio, and the ratio of bending load to shear load.

SYMBOLS

l ring spacing, in.

t thickness of cylinder wall, in.

E Young's modulus, ksi

I moment of inertia of cylinder, in.^{4}

I/c section modulus of cylinder, in.^{3}

$\bar{L}$ distance from point of load application to ring station at far end of test section of cylinder, in.

M maximum bending moment in test section of cylinder, $V\bar{L}$, in.-kips

M_{cr} maximum bending moment in test section of cylinder at cylinder buckling, $V_{cr}\bar{L}$, in.-kips

Q area moment, in.^{3}

R radius of cylinder, in.

V applied transverse shear load, kips

V_{cr} applied transverse shear load at cylinder buckling, kips

V_f applied transverse shear load at cylinder failure, kips

μ Poisson's ratio

σ_{cr} compressive buckling stress of cylinder subjected to a transverse shear load, $\frac{M_{cr}}{I/c}$, ksi

σ_{cr_o} compressive buckling stress of cylinder subjected to a pure bending load, ksi

τ_{cr} shear buckling stress of cylinder subjected to a transverse shear load, $\frac{V_{cr}Q}{It}$, ksi

τ_{cr_o} shear buckling stress of cylinder subjected to a torque load, ksi

TEST SPECIMENS AND TEST PROCEDURES

A photograph of one of the cylinders ready for testing is shown in figure 1. Each test cylinder is comprised of two short buffer bays, one on either end of a test section which is either three or six bays in length. Pertinent dimensions of the test cylinders are given in table I. The stiffening rings were spun from 0.102-inch-thick sheet. They were Z-sections, $2\frac{1}{2}$ inches deep with flanges 1 inch and $\frac{7}{8}$ inch wide. The $\frac{7}{8}$-inch flange served as an attachment flange. The cylinders were fabricated with the with-grain direction of the wall material in the circumferential direction and with a single longitudinal splice on the tension side. The cylinders had radius-thickness ratios R/t that varied from 120 to 475 and had ring-spacing—radius ratios l/R of 1/4, 1/2, and 1.

The specimens were constructed of 7075-T6 aluminum alloy. Typical material properties were used in reducing the data. Young's modulus E was taken as 10,500 ksi, and Poisson's ratio μ was assumed to be 0.32.

The test setup is shown in figure 1. The heavy tip fixture was counterbalanced at its center of gravity in order to eliminate stray bending and shear loads. Rollers which permitted relative motion between the tip fixture and the testing machine were used to restrict the applied load to a vertical shear load, and the testing machine load was transmitted through a pin-and-socket arrangement in order to fix the location of the shear load.

Strain measurements were taken on the neutral axis and on extreme bending fibers of the test cylinders to obtain a check on the stress distribution in the cylinders and to observe the behavior of the cylinder. Small increments of loading were applied to the cylinders. Between load increments, the cylinders were examined for evidence of buckling, and strain readings were taken. The strains were plotted against load and compared with strains computed on the basis of the elementary beam theory. On some of the cylinders with smaller values of R/t, buckling occurred gradually; for these cylinders the measured strains were used to aid in the determination of the buckling load.

Three nominally identical specimens were tested with various ratios of bending load to shear load M/RV. Tests were normally made with nominal value of M/RV of 6, 3, and 1.5. However, for cylinder 16 a value of 7.3 instead of the nominal value of 6 was actually obtained because of an error in locating the testing machine, and in another instance ($R/t = 120$; $l/R = 1/2$), a value of M/RV of 0.75 was used in addition to the usual values.

RESULTS AND DISCUSSION

The loads sustained by the test cylinders at buckling are given in table I. These loads represent the failing load as well as the buckling load for most of the cylinders; when it does not, the failing load is also tabulated. Values of the maximum shear stress and of the extreme fiber stress at the farthest ring station from the point of load application have been computed from the buckling loads by using elementary beam theory $\left(\text{that is, } \tau_{cr} = \frac{V_{cr}Q}{It} \text{ and } \sigma_{cr} = \frac{M_{cr}}{I/c} \text{ where } M_{cr} = V_{cr}\bar{L}\right)$. The buckling stresses are given in table I and are plotted in figure 2 on a load-interaction plot.

Values of σ_{cr_o} and τ_{cr_o} were needed in order to plot figure 2. The value of σ_{cr_o} was taken from the design curves of reference 1 which represent the lower limit of the data obtained from pure bending tests on cylinders similar to the ones used herein. The value of τ_{cr_o} was taken from reference 2 and is applicable to cylinders simply supported at the rings and loaded with a pure torque. Neither reference 1 nor reference 2 is strictly applicable to the application at hand because somewhat different stress distributions were considered in these references than result from a transverse shear load. The use of references 1 and 2 to predict buckling due to transverse shear loads is discussed in reference 3.

The curves in figure 2 are given by the following empirical expressions:

$$\left(\frac{\tau_{cr}}{t_{cr_o}}\right)^3 + \left(\frac{\sigma_{cr}}{\sigma_{cr_o}}\right)^3 = 1.0 \tag{1}$$

and

$$\left(\frac{\tau_{cr}}{1.1\tau_{cr_o}}\right)^3 + \left(\frac{\sigma_{cr}}{1.4\sigma_{cr_o}}\right)^3 = 1.0 \tag{2}$$

The test points are generally bounded by equations (1) and (2) and are generally scattered between the two curves. The scatter (about 40 percent for bending stresses and 10 percent for shear stresses) appears to be independent of the structural parameters l/R and R/t. The 40-percent scatter is a little larger than that observed in the pure bending tests of reference 1. Furthermore, the scatter of the data of reference 1 was small for small values of R/t and approached 40 percent only for the larger values of R/t considered, whereas the scatter of the present data does not appear to have this dependence upon R/t.

The test data for cylinders with $l/R = 1/4$ are not shown in figure 2. The bending strength of these cylinders is probably influenced by the heavy rings employed in the cylinders as indicated in reference 1 for similar cylinders subjected to pure bending loads. The design-chart value of σ_{cr_o} (ref. 1) is not representative of these tests because the test data for cylinders with $l/R = 1/4$ were disregarded in constructing the charts of reference 1. If the test data for cylinders with $l/R = 1/4$ were included in figure 2, most of the test points would fall near the outer fringe of the data shown and many of the points would fall outside the data shown. If, however, actual test data from reference 1 were used to obtain σ_{cr_o}, the high points would fall within the scatter of the data presented; thus, the behavior of these cylinders is consistent with that of those represented in figure 2, if suitable values of σ_{cr_o} are employed.

A photograph of one of the cylinders after being tested to failure is shown in figure 3. The type of buckles exhibited is characteristic of that obtained for the cylinders tested with small values of M/RV. For cylinders with larger values of M/RV, the buckle pattern was usually the familiar type characterized by successive in-and-out buckles along and around the cylinder in the neighborhood of maximum bending stress. In some instances, however, buckles like the one shown in figure 4 were observed. This type of buckle is characteristic of that obtained when the structural dimensions are such that the value of the parameter l^2/Rt is small.

An experimental program similar to the one discussed herein is reported in reference 4. The principal difference between the two programs is in the type of specimens employed. The test specimens in the present investigation were ring-stiffened cylinders which had a short buffer bay on either end of the test section to help distribute the load in the neighborhood of the ends of the test section. The test specimens of the investigation of reference 4 were one-bay type of specimens with the test section clamped between heavy end fixtures. Comparable sets of tests were conducted in references 1 and 5 on cylinders subjected to pure bending loads with the result that considerably higher loads were obtained with the ring-stiffened cylinders than with the one-bay cylinders. This result suggests that the one-bay type of specimen may have irregular stress distributions or "soft spots" in the neighborhood of the ends of the cylinders which have the same deleterious effect as geometrical imperfections such as initial eccentricities and may cause premature local buckling. (See ref. 1).

The bending strength of curved shells is highly dependent upon the initial eccentricities existing in the shell and is practically independent of whether the ends of the cylinder are clamped or simply supported, except for very short shells. The shear strength, on the other hand, is much less dependent upon initial eccentricities but depends to a small extent upon end-support conditions. It might be expected, therefore, that the cylinders of the present investigation would be stronger than those of reference 4 when the loading was predominantly bending (that is, M/RV large) and weaker than those of reference 4 when the loading was predominantly shear (that is, M/RV small). A study of the two sets of data does not substantiate this expectation. Rather, it reveals that the two sets of data differ principally in that the present test results exhibit considerably less scatter than those of reference 4. The scatter, both for small values of M/RV and for large values of M/RV, is less.

As a result of the smaller scatter associated with the present tests as compared with that of the tests of reference 4, higher allowable stresses can be used to represent the lower limit of the present test data than could be used for the data presented in reference 4. The lower limit of the present-test data is given with fair accuracy by equation (1) when complemented by references 1 and 2. (See fig. 2.) Equation (1) is believed, therefore, to be suitable for the prediction of the strength of ring-stiffened circular cylinders in which the rings are heavy enough so that general-instability-type failures do not occur.

CONCLUDING REMARKS

An interaction curve for ring-stiffened circular cylinders subjected to bending and shear is presented. The curve is based on test results from 34 cylinders with heavy rings in which failure was by local instability (between rings) rather than by general instability which involves the simultaneous failure of the cylinder wall and rings. The design curve generally predicts higher failing stresses than curves now in use which are based on tests of one-bay cylinders.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 31, 1958.

REFERENCES

1. Peterson, James P.: Bending Tests of Ring-Stiffened Circular Cylinders. NACA TN 3735, 1956.

2. Batdorf, S. B., Stein, Manuel, and Schildcrout, Murry: Critical Stress of Thin-Walled Cylinders in Torsion. NACA TN 1344, 1947.

3. Peterson, James P.: Weight-Strength Studies of Structures Representative of Fuselage Construction. NACA TN 4114, 1957.

4. Lundquist, Eugene E.: Strength Tests of Thin-Walled Duralumin Cylinders in Combined Transverse Shear and Bending. NACA TN 523, 1935.

5. Lundquist, Eugene E.: Strength Tests of Thin-Walled Duralumin Cylinders in Pure Bending. NACA TN 479, 1933.

TABLE I.- DIMENSIONS AND TEST RESULTS OF CYLINDERS

Cylinder	2R, in.	t, in.	l, in.	Test length, bays	$\bar{L}$, in. (*)	V_{cr}, kips	V_f, kips (**)	σ_{cr}, ksi	τ_{cr}, ksi
1	30.41	0.0340	3.75	6	90.0	3.98	-----	14.5	2.45
2	30.41	.0341	3.75	6	45.0	7.86	8.18	14.3	4.83
3	30.41	.0327	3.75	6	22.5	12.2	13.8	11.6	7.80
4	30.41	.0324	7.50	3	90.0	2.48	-----	9.49	1.60
5	30.41	.0321	7.50	3	45.0	5.68	-----	10.9	3.71
6	30.41	.0335	7.50	3	22.5	7.68	8.12	7.10	4.80
7	30.41	.0324	15.0	3	90.0	2.12	-----	8.11	1.37
8	30.41	.0320	15.0	3	45.0	3.82	-----	7.39	2.50
9	30.41	.0335	15.0	3	22.5	5.58	5.90	5.16	3.49
10	30.43	.0515	3.75	6	90.0	7.72	8.24	18.6	3.13
11	30.43	.0513	3.75	6	45.0	15.0	17.0	18.1	6.10
12	30.43	.0513	3.75	6	22.5	32.5	33.8	19.6	13.2
13	30.43	.0507	7.50	3	90.0	6.54	-----	15.9	2.69
14	30.43	.0511	7.50	3	45.0	12.8	-----	15.5	5.22
15	30.43	.0508	7.50	3	22.5	21.2	-----	12.9	8.70
16	30.42	.0499	15.0	3	111.0	6.10	-----	18.6	2.55
17	30.42	.0496	15.0	3	45.0	12.4	-----	15.5	5.21
18	30.42	.0494	15.0	3	22.5	15.0	15.8	9.41	6.33
19	30.46	.0826	3.75	6	90.0	22.5	27.1	33.6	5.69
20	30.46	.0827	3.75	6	45.0	47.5	57.2	35.4	11.9
21	30.46	.0824	3.75	6	22.5	87.0	99.9	32.7	22.0
22	30.46	.0825	7.50	3	90.0	22.3	-----	33.4	5.64
23	30.46	.0825	7.50	3	45.0	43.6	-----	32.6	11.0
24	30.46	.0821	7.50	3	22.5	67.3	-----	25.3	17.1
25	30.45	.0765	15.0	3	90.0	20.2	-----	32.7	5.50
26	30.45	.0767	15.0	3	45.0	33.4	-----	26.8	9.08
27	30.45	.0767	15.0	3	22.5	39.6	40.4	15.9	10.8
28	30.50	.126	7.50	3	90.0	56.0	60.0	54.5	9.25
29	30.50	.126	7.50	3	45.0	115.	-----	55.9	19.0
30	30.50	.125	7.50	3	22.5	177.	-----	43.6	29.5
31	30.50	.125	7.50	3	11.3	194.	-----	23.9	32.4
32	30.50	.124	15.0	3	90.0	48.0	50.4	47.5	8.05
33	30.50	.125	15.0	3	45.0	96.5	-----	47.5	16.1
34	30.50	.125	15.0	3	22.5	131.	-----	32.2	21.8

*$\bar{L}$ is distance from load to far end of test section of cylinder.

**Failing loads are tabulated only for cylinders with post-buckling strength.

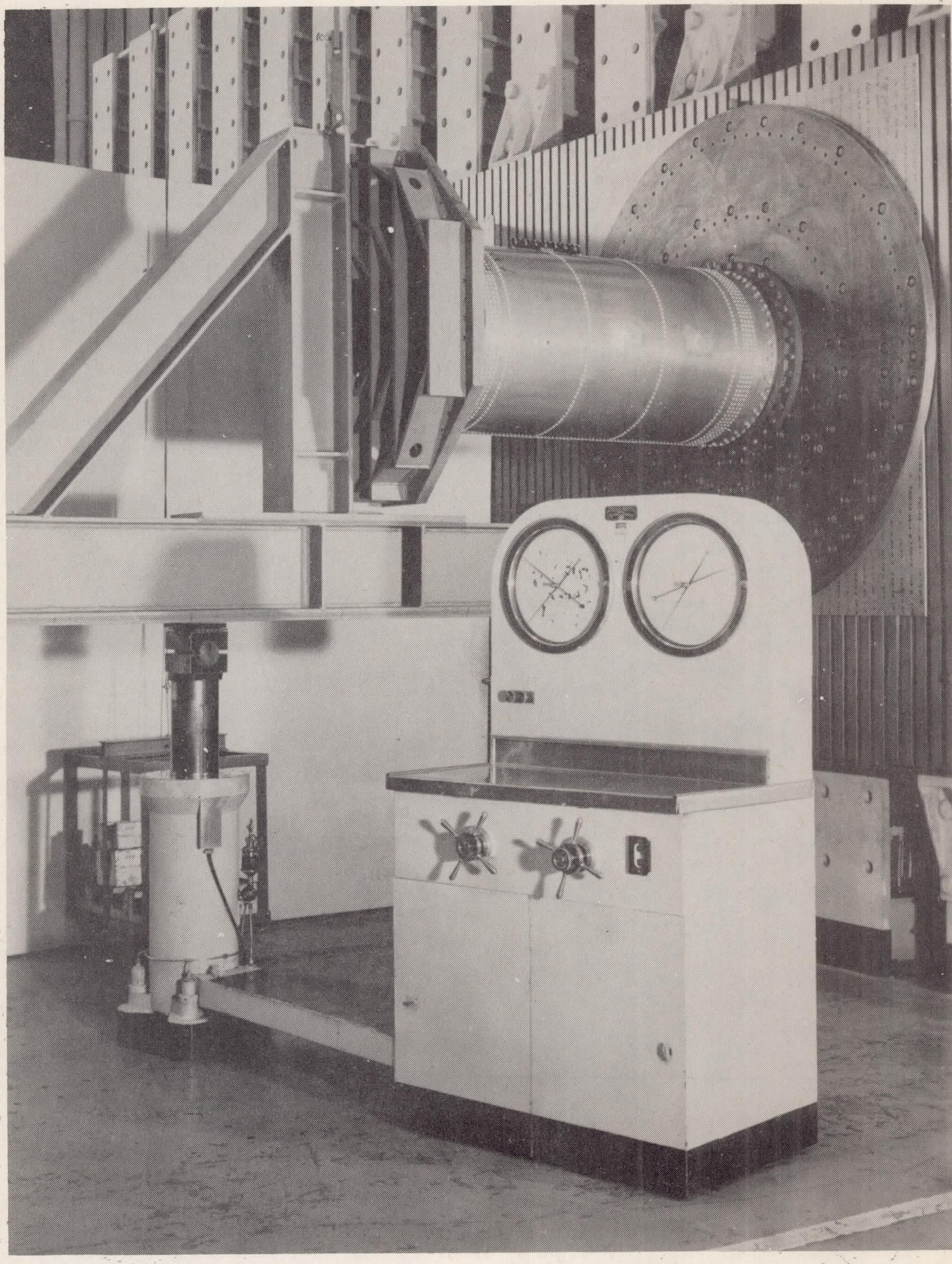


Figure 1.- Test setup. L-58-942

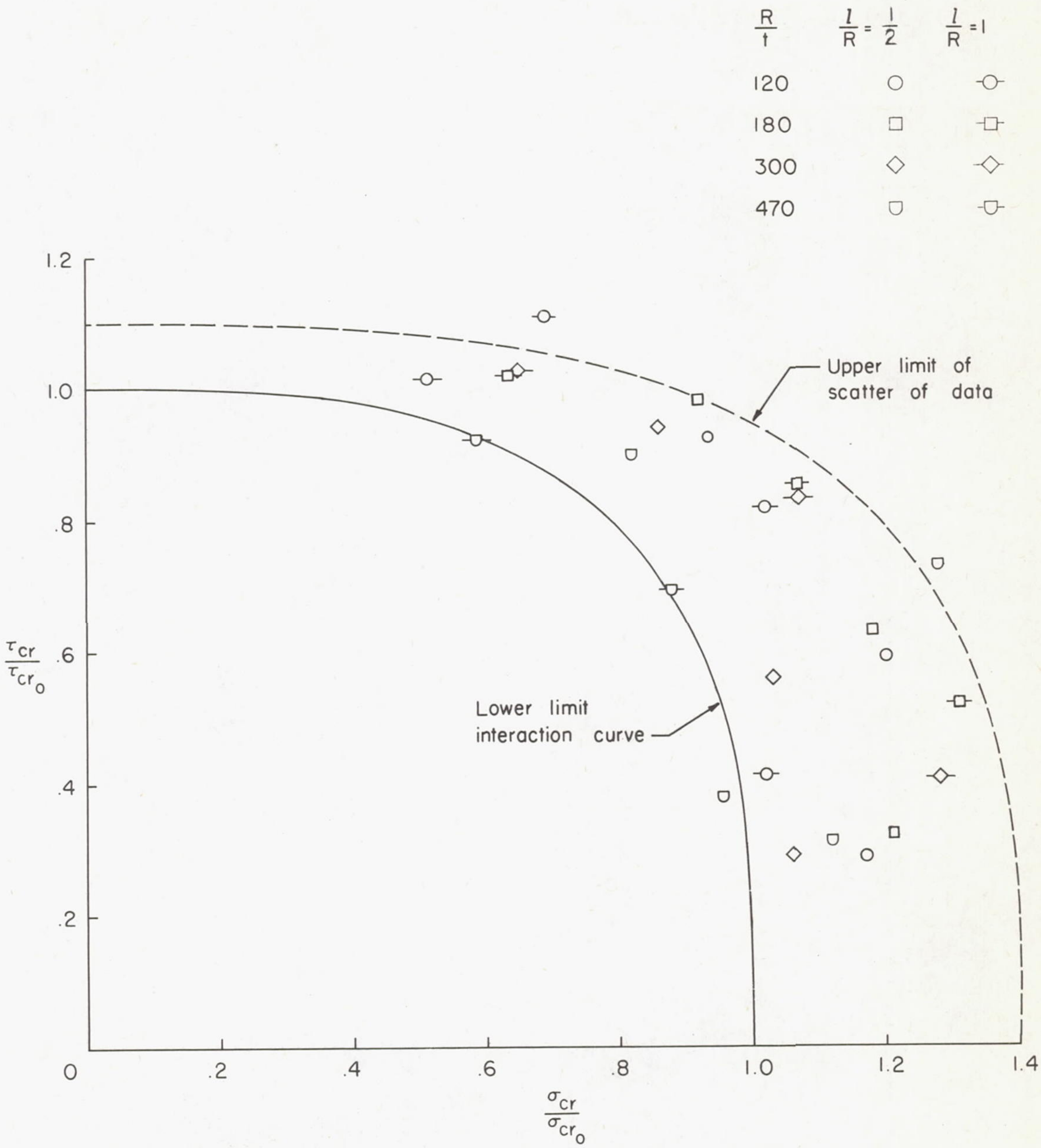
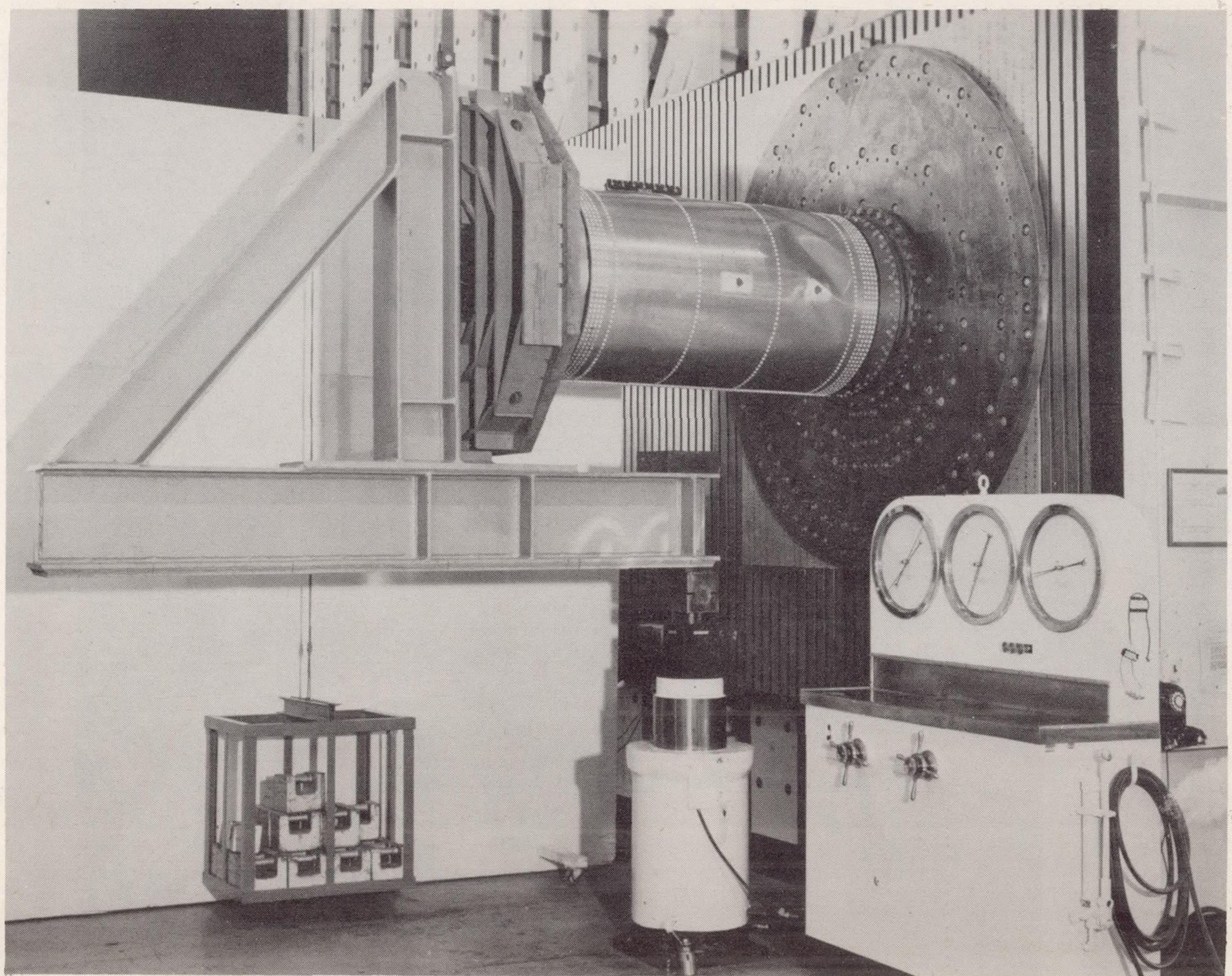
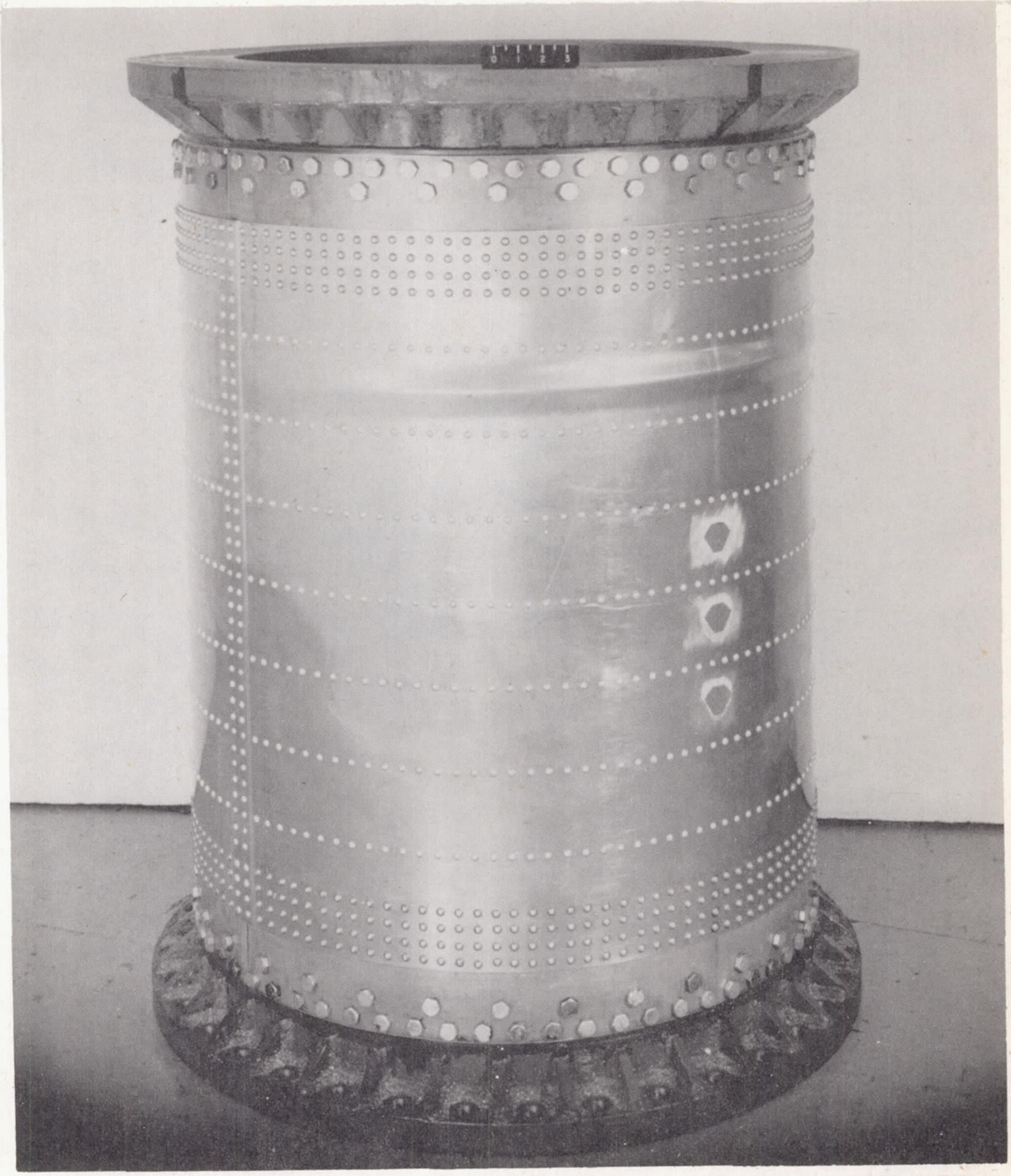


Figure 2.- Test results.



L-58-1053

Figure 3.- Typical failure of cylinder with small value of $\frac{M}{RV}$.



L-89649

Figure 4.- Typical failure of cylinder with small value of $\frac{l^2}{Rt}$ and large value of $\frac{M}{RV}$.